

Sub A'FINITE LOCAL ENHANCEMENT
OF COLOR VIDEO SIGNALS

This invention relates to video signal processing and more particularly to processing color video signals so as to enhance the video images produced by such signals.

Background Of The Invention

The design of picture reproduction systems involves consideration of a number of factors which affect how a picture is perceived by the human eye, including but not limited to the following factors: (1) sharpness or pictorial clarity, (2) contrast between light areas, dark areas and the related background illumination, and (3) realistic color values. In this context it should be noted that the eye does not respond equally to radiated energy of all visible wavelengths, there is a wide variation in response between observers, and the eye's response is a function of light intensity. See W. C. Hughes, "Electronic Engineers' Handbook", 1st Ed., pp. 20-3, 20-4, McGraw-Hill 1975.

Color video (television) standards are based on the manner in which the eye perceives colored light. In color video systems a wide range of colors can be reproduced for reception by the eye by the addition of only three monochromatic light sources, red, green and blue. The color signals produced by a video camera are encoded before being transmitted to a television receiver or other video display device, the encoded signals comprising a luminance information signal and color signals. As explained by Hughes (supra), p.20-3, the luminance of a surface is the effect on the average eye of the light emitted by a unit area of the surface. Luminance is the integrated effect of the eye response and the visible light power radiated by the surface, both of which are functions of wavelength.

Spatial frequency is the frequency at which an image changes over distance. Luminance is more significant than color at higher spatial frequencies. The human eye response to high spatial frequency information is not the same as it is for low spatial frequency information. Accordingly efforts have been made to process spatial frequency video information signals for the purpose of enhancing the sharpness of reproduced video images. One such effort is represented by U.S. Patent No. 4,721,998, issued 1/26/88 to W. E. Glenn for "Method And Apparatus For Processing Color Video Signals". Other such efforts may be known to persons skilled in the art.

The idea of enhancing the images produced by a video camera is particularly intriguing in the case of producing images for surgical or medical purposes. For such purposes, video cameras are utilized in the form of video endoscopes, so-called because the camera is embodied as an integral part of the endoscope, or as an accessory that is attached to the back end of a conventional optical endoscope. In many surgical procedures it is often helpful to enhance color video images in a way which will add to the information perceived by the medical specialist. Details such as small or large blood vessels, differences in tissue condition or tissue types, and the margins between them can be made more distinct and informative by appropriately electronically enhancing the image reproduced by use of the video signals.

Objects And Summary Of The Invention

A primary object of the invention is to provide a novel method of processing video signals representative of an image so as to produce an enhanced reproduction of that image, or a portion thereof.

Still another object is to provide a method and apparatus for electronically processing video signals representing images of an object or scene so that details of some portion or all of said object or scene are enhanced in the video display reproduction of said images.

These and other objects are achieved by deriving one or more digital color-representative signals and a digital luminance signal from a suitable source, for example, a color video camera or a video recording system or from previously processed video signals. The digital luminance signal is passed through a low-pass FIR (finite impulse response) filter that removes the higher spatial frequency components. The resulting low pass digital data is subtracted from the original luminance image data, leaving the digital data representing the high-pass image components that were rejected by the low-pass filter. The high-pass digital data for each pixel is subjected to amplification ("boost") according to a function of the low-pass data value at that pixel. Essentially the high frequency components of different pixels in an image are boosted differently according to the low spatial frequency components of the same pixels. The lower the value of the lower spatial frequency components, the more the higher spatial frequency components get boosted. The low-pass data and the selectively boosted high-pass data are subsequently added together to form the finite local enhancement version of the luminance data. The finite local enhanced luminance data is used to generate a display of the observed image with all or part of the displayed image being enhanced. To maximize the benefit of the enhancement process, at each pixel the enhanced values of luminance are compared against predetermine minimum and maximum values allowed for image data. Values beyond the valid range are set equal to the predetermined minimum or maximum values respectively.

The invention enables different degrees of enhancement of the light and dark areas of the image, with the darker parts of the picture getting more boost than the lighter areas, unless the operator deliberately selects some other result. The operator may interface with the boost table by selecting a region of the image to be enhanced, and/or by selecting a profile of boost values (less and/or greater than unity) to produce a desired enhancement result.

Other features and advantages of the invention are described or rendered obvious by the following text and the accompanying drawings.

The Drawings

Fig. 1 is a block diagram illustrating a video signal processing system embodying the present invention;

Fig. 2 is a block diagram that generally illustrates how the color video signals from a camera or other sources are processed to generate a luminance signal and a chrominance signal;

Fig. 3 is a block diagram illustrating a preferred embodiment of the luminance-enhancing system of the present invention;

Figs. 4A-4H are schematic examples of eight different gain tables; and

Figs. 5A-5E are schematic examples of different regional control tables.

In the drawings, like components are identified by like numerals.

Description of Preferred Embodiment of the Invention

Sub A2 Referring to Fig. 1, there is shown a video apparatus comprising a luminance-enhancing digital video signal processing system 4 that embodies the present invention. The processing system 4 is adapted to receive and process video signal inputs derived from a suitable source, e.g., by RF transmission from a remote transmitter, a video recorder, or a video camera. In Fig. 1 the source of the color video signal input is a color television camera 2. By way of example but not limitation, the camera may be a stand alone conventional color television camera or a video camera as incorporated in or coupled to an endoscope or other apparatus. Endoscopes incorporating video cameras are well known and are exemplified by the devices disclosed in U.S. Patents Nos. 4,745, 471 issued to K. Takamura et al.; 4,868,645 issued to K. Kobayashi; 5,577,091 issued to N. Akui et al.; and 5,891,015, issued to F. Strähle. It is to be understood that if the multi-component electrical/output signal from the camera is in analog form

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cancel* (which currently is the most common format), it is necessary to subject it to analog-to-digital conversion by means of an A/D converter 3 before applying it to the signal processing system 4.

The digital output of signal processing system 4 may be applied without material change to a video display device 6 and/or a video recorder 8 and/or a transmitter 10 if the latter are digitally-operating devices. Alternatively, the digital output signal from signal processing system 4 may be subjected to digital-to-analog conversion via a D/A converter 5 if display 6, recorder 8 and transmitter 10 are analog rather than digital devices.

Referring now to Fig. 2, digital red (R), green (G), and blue (B) color component signals derived from camera 2 or another source are applied to a summing matrix 14 where they are combined to produce a digital luminance signal **Y** and a digital chrominance signal **C** which constitutes phase-encoded RGB color data. The **Y** and **C** digital signals includes timing data for keeping track of pixels. As is obvious to persons skilled in the art, the color component data output of summing matrix 14 may consist of other digital color-representative signals, e.g., conventional color difference signals such as R-Y and B-Y, or other forms of digital signals which include, in any form, color components data.

Turning now to Fig. 3, the digital signal processing system 4 comprises a filter 16, a subtracting unit or subtractor 18, horizontal and vertical counters 20 for tracking pixels, a regional control tables memory unit 22 containing a plurality of selectively accessible digital regional control tables, a regional selection control 23, a gain tables memory storage unit 24 containing a multiple of accessible stored digital gain tables, a multiplier 26, a summing unit or adder 28, a limiter 30, and a compensating delay device 32. The filter 16 is a low-pass FIR (finite impulse response) filter that removes higher spatial frequency components, from the electrical signal output **Y** of summing matrix 14. The storage units 22 and

24 may take various forms, e.g., a storage disk or one or more E-proms forming part of a computer.

The regional control memory unit 22 comprises a memory unit in which are stored one or more region selection control tables for generating gain table select command signals that are used to selectively access the gain tables stored in storage unit 24, whereby to vary application of the gain (boost) factors that are applied to multiplier 26 on a pixel-to-pixel basis and thereby vary the enhancing effect of processing system 4 on selected portions of the image represented by luminance signal **Y** and chrominance signal **C**. The region selection control 23 is adapted to respond to operator inputs to modify operation of signal processing system 4 by selecting specific regional tables from memory unit 22, so as to vary the area of the observed image that is to be enhanced and/or vary the degree of enhancement.

The storage unit 24 contains in memory a plurality of different gain tables that provide different gain factors for different low spatial frequency values. Preferably also the storage unit 24 contains in memory one or more tables that provide gain factors less than unity

As is obvious to a person skilled in the art, certain of the foregoing components may comprise portions of a digital computer. Preferably, but not necessarily, subtractor 18, counters 20, regional table memory unit 22, regional control 23, gain tables memory unit 24, multiplier 26, adder 28 and limiter 30 comprise portions of a digital computer, as indicated by the broken line 7, with the operator inputs to the computer being fed in by keyboard or voice commands. Also two or more of the foregoing devices may be combined into one discrete unit or location, e.g., memory units 22 and 24 may comprise a single E-prom or separate storage addresses on a single hard disk.

The chrominance signal **C** is passed through the compensating delay device 32 which is adapted to delay that signal by an amount sufficient to have it arrive at video display device 6 and/or video recorder 8 and/or transmitter 10 in time-

step with the enhanced luminance signal, i.e., at the output end of signal processing system 4 the chrominance data for each pixel is coincident in time with the enhanced luminance data for that pixel passed by limiter 24, which also includes timing and pixel location data.

Still referring to Fig. 3, the luminance signal Y , which also includes timing and pixel location data, is applied to low-pass filter 16, and also to subtracting unit 18 and horizontal and vertical counters 20. The filter 16 removes the higher spatial frequency components from the luminance signal Y , producing a modified luminance signal $Y1$ that contains the low spatial frequency image data components of the original luminance signal Y . The low-pass digital output $Y1$ of filter 16 is applied to subtracting unit 18, where its low spatial frequency image data is subtracted from the luminance image data of the original luminance signal Y , with the result that the output of subtracting unit 18 is a digital luminance signal $Y2$ that consists of the high-pass image data components that were rejected by the low-pass filter. The low-pass digital output $Y1$ of filter 16 is also applied to the multiple gain tables memory unit 24 and to adder 28.

The counters 20 track the pixels, and the output signals of those counters are applied to regional memory unit 22, which also is adapted to receive operator inputs from regional selection control 23 for modifying the selection of the regional control tables stored in regional table memory unit 22, whereby to vary the gain table select command signal fed from regional table memory unit 22 to gain tables memory unit 24.

The operator inputs to region selection control 23 may be applied by keyboard or voice or by other suitable means used for inputting instructions to a digital computer. Programming such instructions for region selection control 23 may be accomplished in various ways obvious to persons skilled in the computer programming art.

The operator inputs are in the form of instructions for selectively causing the processing system 4 to produce the following results: full screen enhancement

in which the entire image is subjected to the luminance enhancement process, regional screen enhancement in which only a selected region or regions of the image is enhanced, split screen enhancement in which the image is split into two side-by-side portions and only one portion is enhanced, adjustment of the overall enhancement level, adjustment of the size of the region being enhanced, deliberate reduction of the luminance values in the areas surrounding the area undergoing luminance enhancement, and effectively nulling or by-passing the enhancement process. Thus, for example, full screen enhancement involves enhancing all of the pixels of each image, while regional enhancement involves enhancing only selected pixels. Nulling or bypassing the enhancement process is achieved by programming the region selection control so that it causes the memory unit 24 to provide a gain factor of unity to multiplier 26..

The gain table select command signal output of regional control memory unit 22 is applied to memory unit 24 and functions to (a) select which of the various gain tables stored in memory unit 24 is read to determine the gain to be used by multiplier 26 to enhance the high frequency data luminance signal **Y2**, and (b) determine which of the pixels of the image are to be enhanced according to the operator inputs, if any. Depending upon the operator input(s), the gain table select command signal output of memory unit 22 also may function to apply a specific gain factor to multiplier 26. Thus, for example, if an image softening effect is desired for a specific region, the region control 23 may be instructed by the operator to regional control table in memory unit 22 that will result in a gain table select command that selects a gain table that provides a gain less than unity for all values of **Y1** for pixels that fall within a selected region. It is preferred that processing system 4 be programmed so that, in the absence of any operator input, its normal mode of operation is to apply the enhancement process to all of the pixels of the image represented by the incoming luminance and chrominance signals **Y** and **C**.

The low pass digital signal **Y1** is applied to gain tables memory unit 24 so that, regardless of which of its gain tables is selected by the gain table select command signal output of memory unit 22, the gain factor represented by the gain signal output from memory unit 24 will vary according to the low pass data value of low pass signal **Y1**.

The digital high pass data signal output **Y2** of subtracting unit 18 is applied to multiplier 26 where it is amplified according to the gain (boost) factor applied to the multiplier from the multiple gain memory unit 24. The result is a boosted high pass luminance signal **Y3**. The latter is summed with the low pass luminance signal **Y1** in adder 28 so as to produce an enhanced luminance signal **Y4**. That enhanced luminance signal **Y4** may be applied without limitation to the video display device 6 and/or video recorder 8 and/or transmitter 10 in time-step with the chrominance signal **C**. However, in order to maximize the benefit of the enhancement process, it is preferred to pass the signal **Y4** through limiter 30 which is adapted to compare the enhanced luminance values with predetermined maximum and minimum values and to (1) change those values that are below the predetermined minimum value so that they equal that minimum value, and (2) change those values that exceed the predetermined maximum value so that they equal the maximum value.

To summarize the operation of processing system 4, each pixel of high-pass image data represented by high pass data luminance signal **Y2** is subjected to amplification ("boost") according to a gain factor provided by the gain tables in storage unit 24 that varies as a function of the low-pass data value at that pixel represented by the low-pass luminance signal **Y1**. This enables different degrees of enhancement of the light and dark areas of the image. The operator may interface with the gain table by selecting, via the signal output of region selection control 22, a specific region of the image to be enhanced and a profile of boost values which produce the enhancement desired. The signal **Y4**

represents the finite local enhancement version of the luminance data contained in the original luminance signal Y .

Figs. 4A-4H provide examples of eight different gain tables stored in gain table memory unit 24. For convenience the gain tables in Figs. 4A-4H are numbered from 0 to 7 so as to distinguish one from the other. The first three gain tables, tables 0, 1 and 2 (Figs. 4A-4C), provide no enhancement, while the other five tables, tables 3 to 7 (Figs. 4D-4H), provide five different enhancement levels. Fig. 4A illustrates a gain table for applying a gain of 0 (zero) to multiplier 26 for all low pass frequency values (from black to white). This table is used for regions in which the high frequency values are to be eliminated completely, thereby softening the image as much as possible. Fig. 4B shows a gain table in which a gain of 0.5 is passed to the multiplier in response to all low pass frequency values. This gain table is used where it is desired to soften a region from its normal appearance partially. Fig. 4C differs in that a gain of 1 is provided in response to all low pass frequency values. This gain table is used where it is desired to show pixels with no modification of their normal luminance value. Fig. 4D represents the first of five different enhancement levels. In the case of Fig. 4D, the gain non-uniformly varies from 1.3 for low frequency values representative of black image areas to 1.0 for low frequency values representative of white image areas. The table of Fig. 4E represents a second enhancement level. It varies the gain in equal decrements from 1.7 for low frequency values representative of black image areas to 1.0 for low frequency values representative of white image areas. Fig. 4F shows a gain table for a third enhancement level. In this case the low frequency values representative of black image areas are provided with a gain of 2.7, with the gain factors changing in a non-uniform manner to a low of 1.0 for low frequency values representative of white image areas. Fig. 4G provides a gain table for a fourth enhancement level, wherein the gain factors vary non-uniformly from 3.5 for black image areas to 1.0 for white image areas. Fig. 4H provides a fifth enhancement level,

wherein the gain factors vary non-uniformly from a maximum value of 4.0 for black image areas to a value of 1.0 for white image areas.

Figs. 5A-5E provide schematic illustrations of selected examples of regional control tables stored in regional control table memory unit 22. In each figure, the table is represented as consisting of 9 squares on each side, with each square representing a pixel and pixel location. Additionally each pixel has a number representing one of the eight gain tables of Figs. 4A-4H.

It is to be understood that the number of pixels that are processed by the invention will vary according to the number of pixels making up the image-receiving surface of the electronic imaging device (CCD array or like solid state device) that is used to generate electrical output signals representative of optical images focused on that surface. Accordingly it should be understood that in practice each regional control table will consist of data for a substantially greater number of pixels than are represented in Figs. 5A-5E.

In Fig. 5A, a small rectangular center region consisting of 9 squares, each identified by the numeral "7" to indicate the gain table of Fig. 4H), is surrounded by other squares each identified by the numeral "0" to indicate the gain table of Fig. 4A. Accordingly the pixels assigned the numeral "0" will the maximum softening effect since the table of Fig. 4A has a uniform gain of zero (0.0), while the pixels identified by the numeral "7" will be subjected to the gain factors of the gain table of Fig. 4H. In Fig. 5B, the enhanced region is enlarged to consist of 25 center located pixels, with the remaining surrounding pixels being softened due to being subjected to zero gain according to the table of Fig. 4A. Fig. 5C also has a small rectangular center region consisting of 9 pixels each identified by the numeral "7" to indicate that they will be enhanced according to the gain table of Fig. 4H, but in this case the immediately adjacent pixels on all four sides of the rectangular center region are identified by the numeral "2" indicative of the gain table of Fig. 4C, and the immediate next rows of pixels are identified by the numeral "1" indicative of the gain table of Fig. 5B, while the outermost pixels are

identified by the numerical value of "0" indicative of the gain table of Fig. 4A. The net effect is that the pixels in the center region will be enhanced by subjecting them to a gain factor as determined by the table of Fig. 4H, and that enhanced center region of the image is surrounded by pixels that have a graduated "softer" regions that subjected to gain factors determined by the gain tables of Figs. 4C, 4B and 4A. Fig. 5D illustrates a split screen, wherein five columns of pixels are enhanced by subjecting them to gain factors according to the gain table of Fig. 4H, and the remaining four rows are characterized by no enhancement in luminance due to being subjected to the gain factor of unity according to the gain table of Fig. 4C ("enhancement level 2). In Fig. 5E all of the pixels identified by the numeral "7", indicating that they are all subjected to enhancement according to the gain table of Fig. 4H.

It is to be understood that other regional control tables may be stored in memory unit 22 in addition to or in place of the regional control tables shown in Figs. 5A-5e. Also other gain tables may be incorporated in addition to or in place of the gain tables shown in Figs. 4A-4H. The system may be programmed so that the selection of particular regional control tables is automatic. Alternatively, and preferably, the system is programmed so that it automatically accesses a regional table is like that shown in Figs. 5A-5C, so that the center portion of an image is enhanced and the surrounding regions are not enhanced or in fact subject to a gain less than unity. Predetermined selection of other region control tables may be programmed into the system for particular applications.

The invention provides a luminance enhancement system that is reliable and provides a wide selection of image enhancement formats. Also the system is compatible with and may be embodied in existing imaging systems. It has been found to be particularly advantageous in enhancing images produced by a video endoscope so as to make it easier to discern details and differences in live tissue. In this respect, use of a regional control table patterned like those

represented in Figs. 5B and 5C has been shown to greatly increase the ability of a surgeon to discriminate between different areas of tissue being inspected by means of a video endoscope. A further advantage of the invention is that the enhanced luminance and colorance signals may be readily converted to analog formats for use in operating analog-type display, video recording or video transmitting apparatus. Alternatively, those digital data signals may be used to operate digital display, recording or transmitting apparatus.

It is recognized that persons skilled in the art may readily discern that the invention is susceptible to a number of changes, and in particular that the substantially entire processing system 4 may be embodied in or take the form of a digital computer. Still other changes will be obvious to persons skilled in the art from the foregoing specification. Accordingly the invention shall be deemed to be defined by the following claims which are to be construed in light of the foregoing specification